The physics of black hole binaries: geodesic properties, quasinormal modes and interaction with fundamental fields

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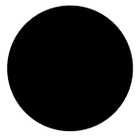
Black hole binary

- Compared with single BH, BH binary spacetime is not deeply understood.

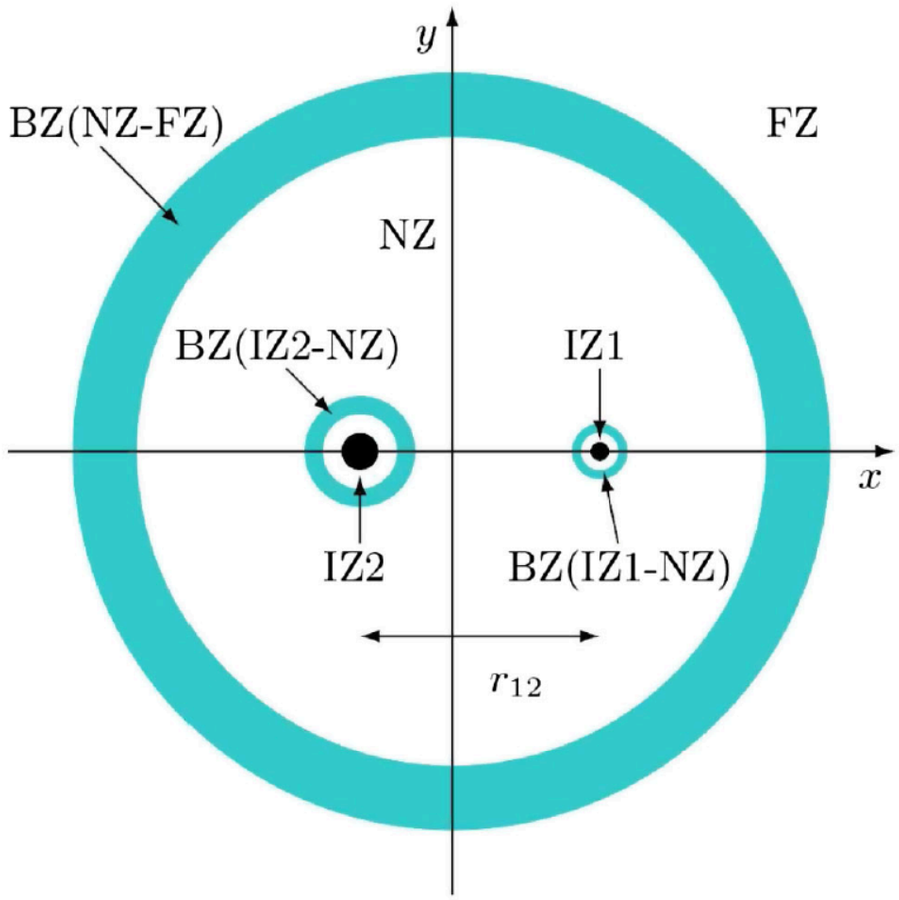
Black Hole	Black Hole Binary
- closed null geodesic	- “Global ” closed null geodesic ?
- Quasi normal mode	- “Global” QNM ?
- Superradiance	- amplification mechanism ?
	

Approximated BHB spacetime

- Construction of the metric $A = 1,2$

  ref: PRD89,084008(2014)

  - Inner Zones (IZ) : $0 < r_A \ll r_{12}$
    - a perturbed Schwarzschild BH
  - Near Zone (NZ) : $m_A \ll r_A \ll \lambda$
    - PN approximation
  - Far Zone (FZ) : $\lambda \ll r < \infty$
    - PM approximation
  - Buffer Zone (BZ)
    - Asymptotic matching
- Due to this metric, numerical simulation becomes faster.



BHB spacetime (BH1, BH2)

r_{12} : BH separation

$m_1 = m_2 = M/2$

a. global closed null geodesic
b. global QNM
c. amplification mechanism

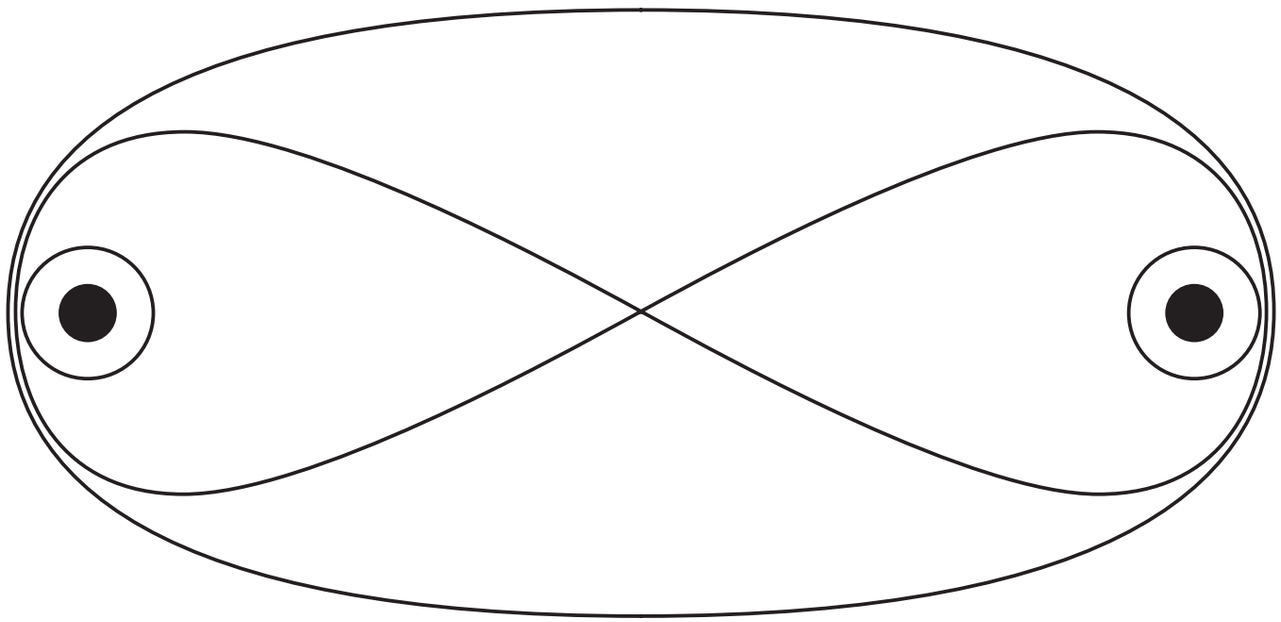
a. global closed null geodesic

b. global QNM

c. amplification mechanism

Global closed null geodesic

- We solved null geodesic on the BHB metric.
- And, we found three types of “nearly” closed null geodesics.
  - Geodesic surrounding each BH
  - A global non-intersecting geodesic
  - An eight-shaped geodesic



a.s.c.

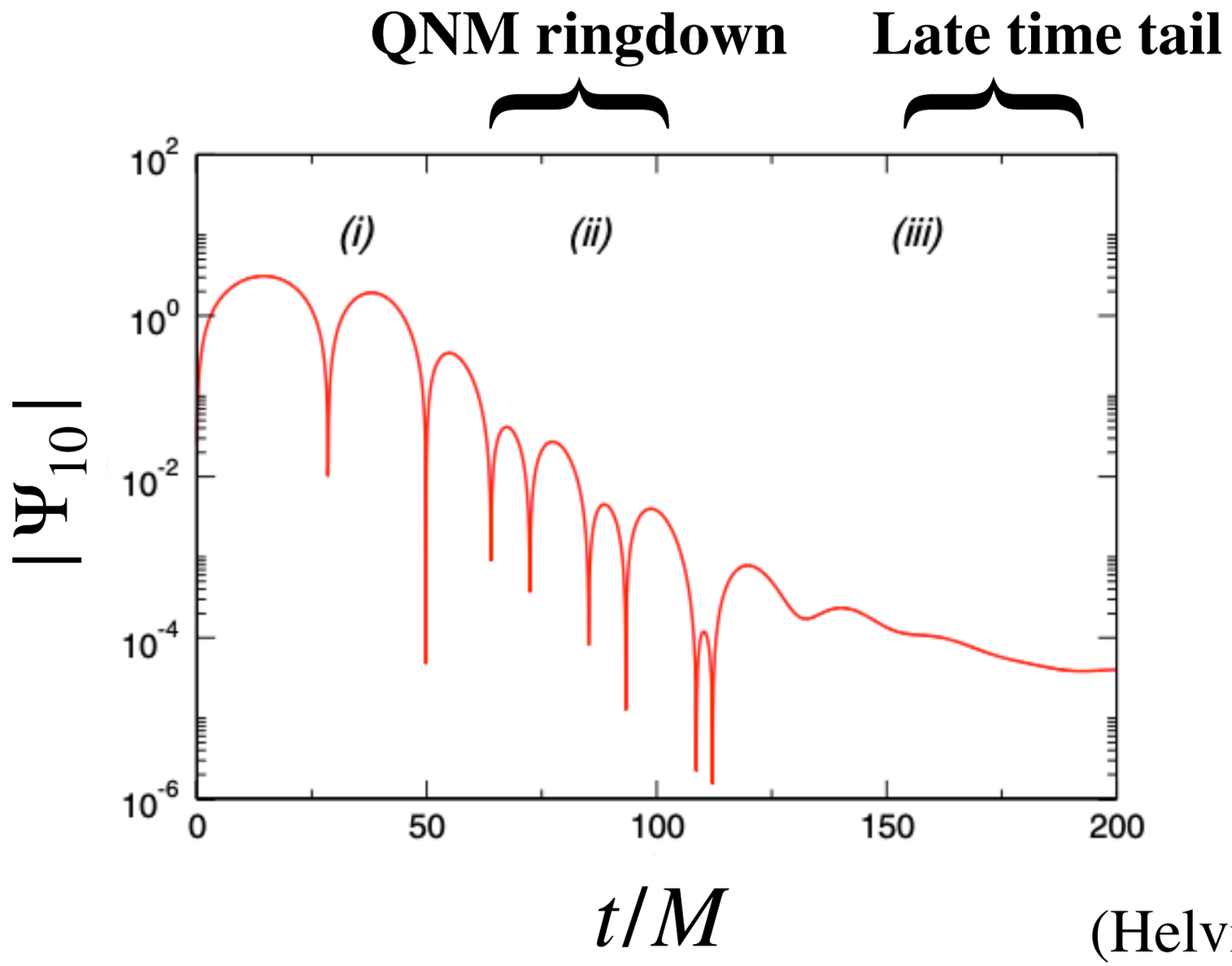
a. global closed null geodesic

b. global QNM

c. amplification mechanism

Scalar field around BH

- Late time behavior of scalar field reflects spacetime properties.

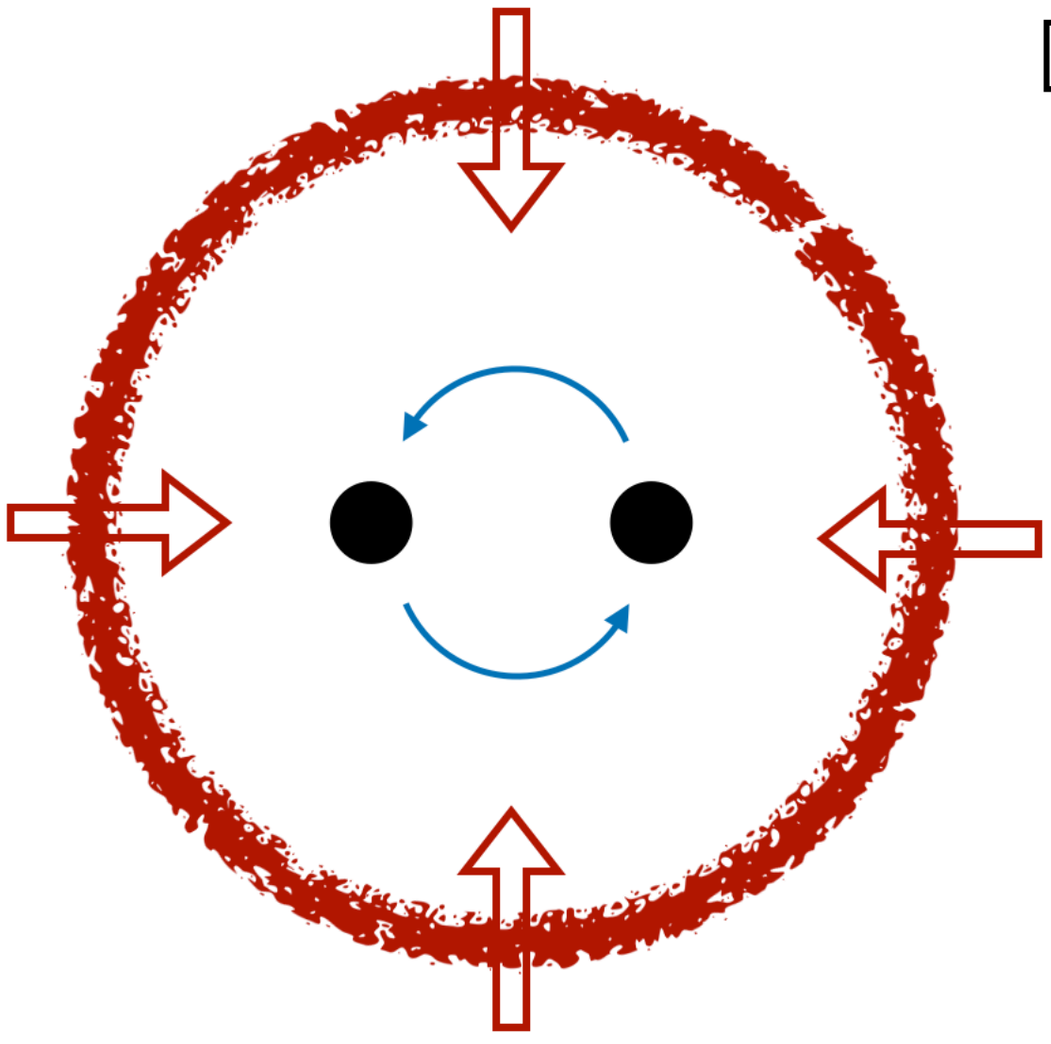


(Helvi et al (2013))

Simulation

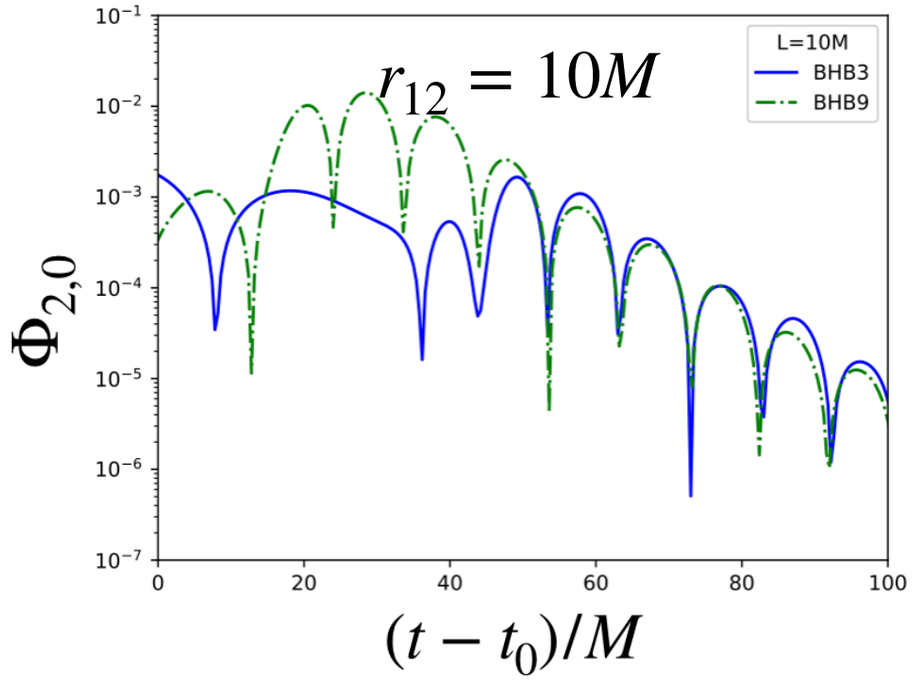
- We solved massless scalar field on the BHB metric.
- Initial data : Spherically symmetric ingoing wave

$$\Box \Phi = 0$$

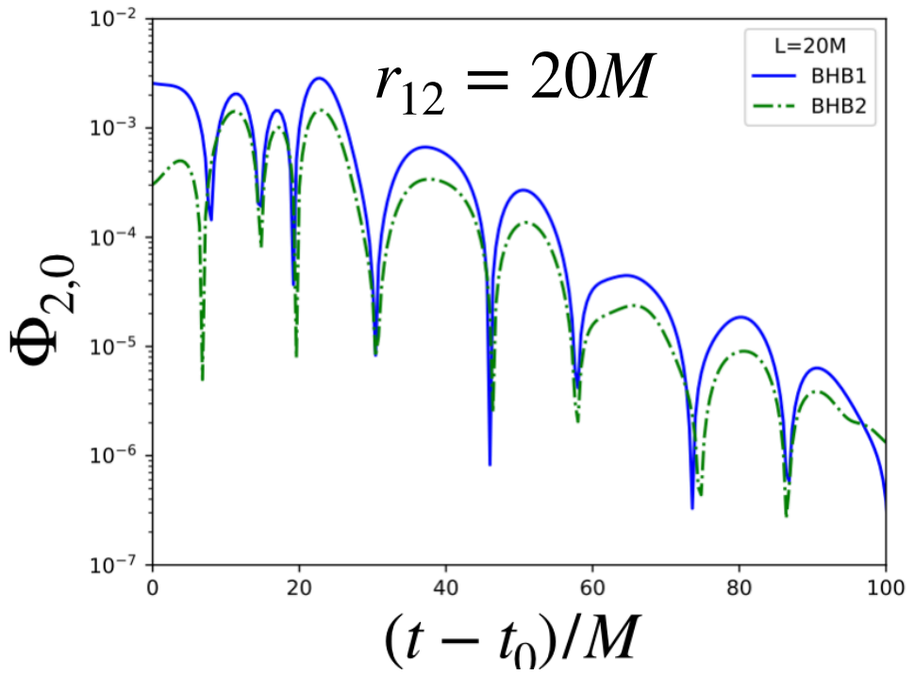


Global QNM

- The late behavior does not depends on the initial data.



$T \simeq 18M$

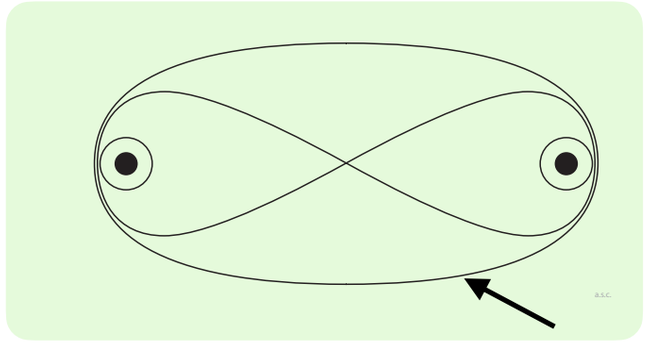


$T \simeq 28M$

- The periods of QNM are consistent with the expected period from global null closed geodesic.

$$T_{\mathrm{QNM}} \simeq L + 8M$$

➡ This is “global QNM”



a. global closed null geodesic

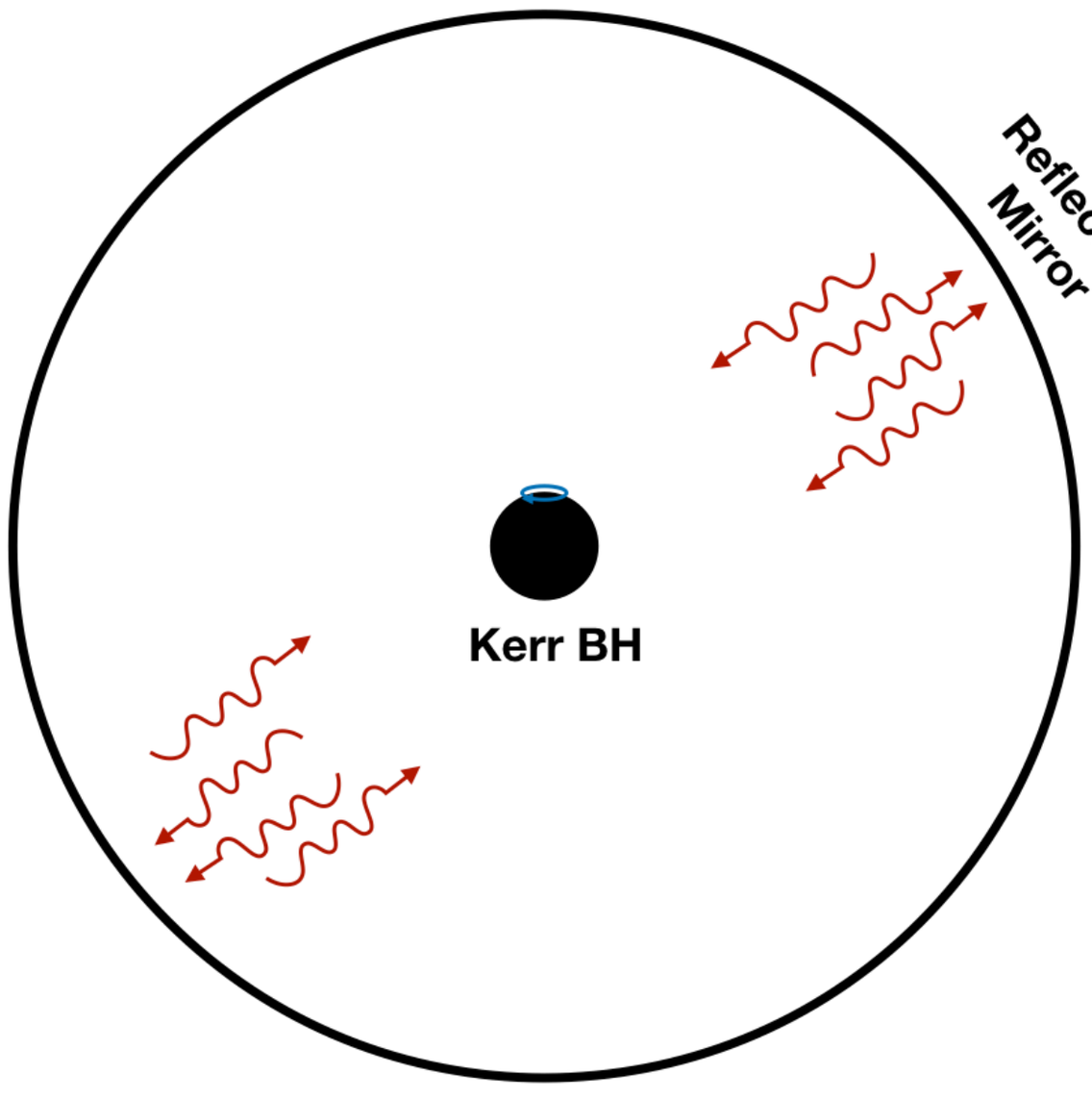
b. global QNM

c. amplification mechanism

Amplification mechanism

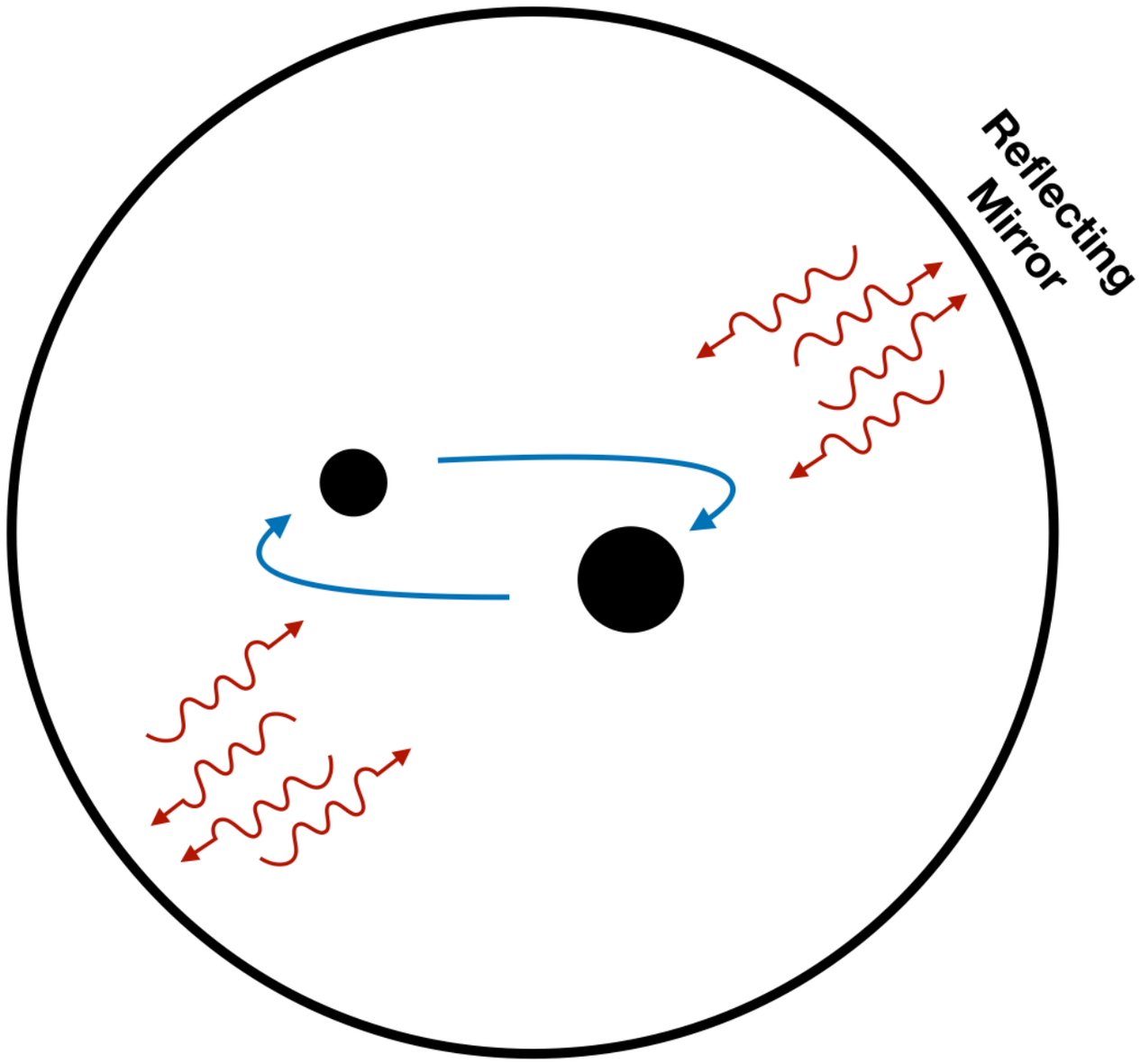
Black hole bomb

cf: super-radiant instability



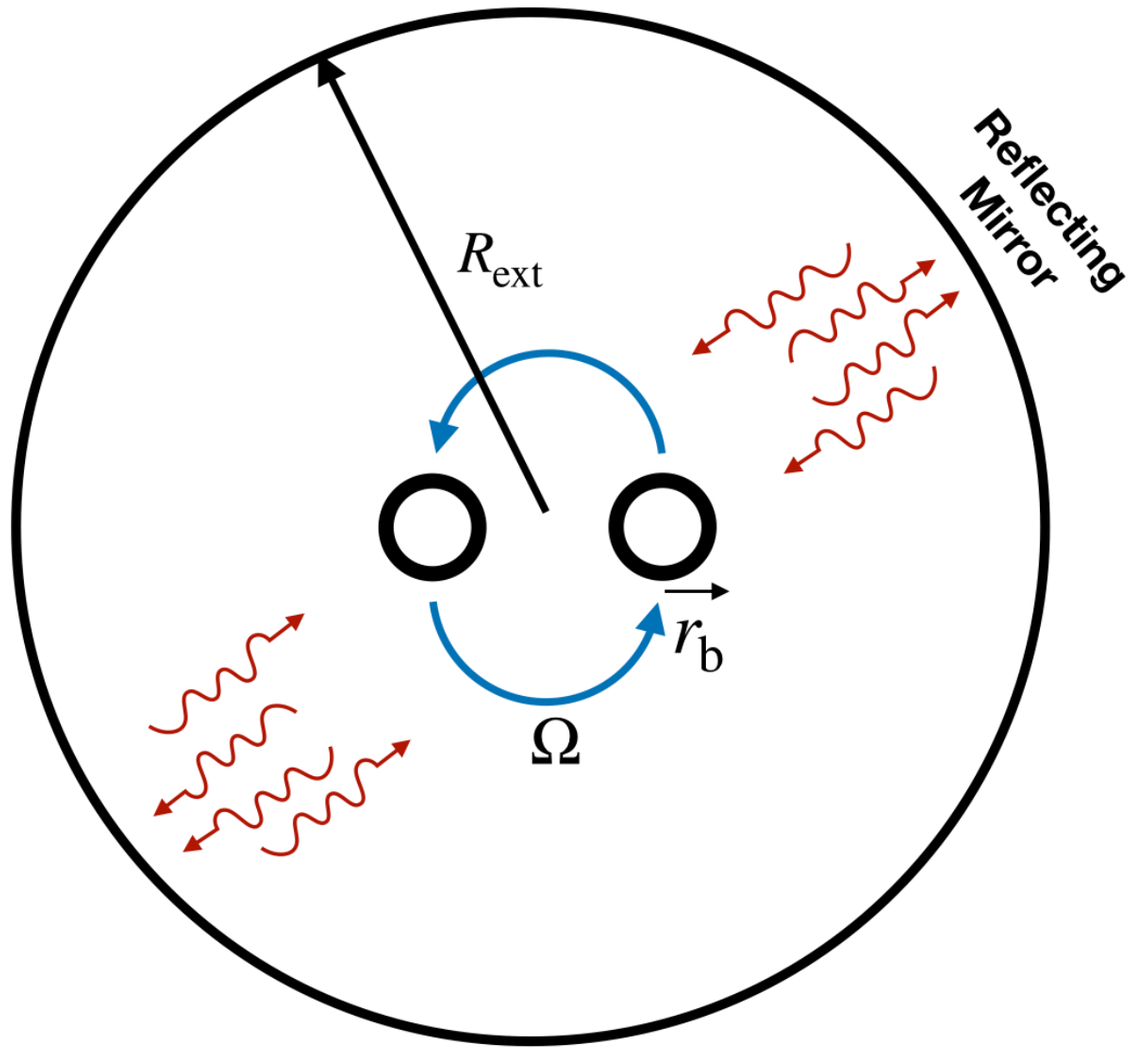
Amplification mechanism

Black hole binary bomb (?)
amplification mechanism (?)



Toy model

- Massless scalar field inside a cavity with a binary of two reflecting objects in 2+1 Minkowski



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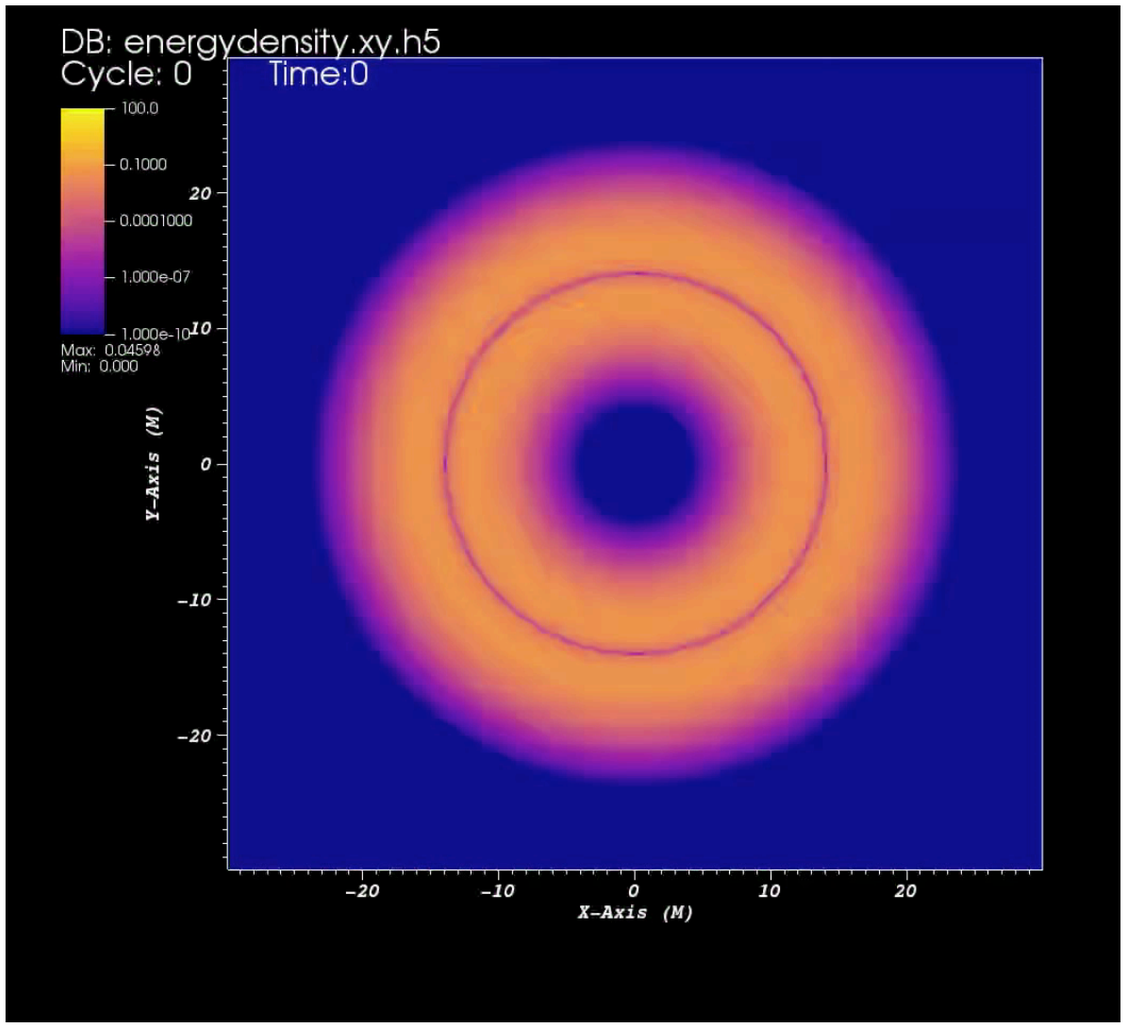
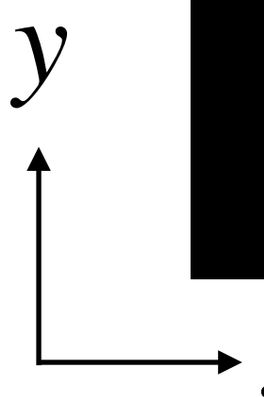
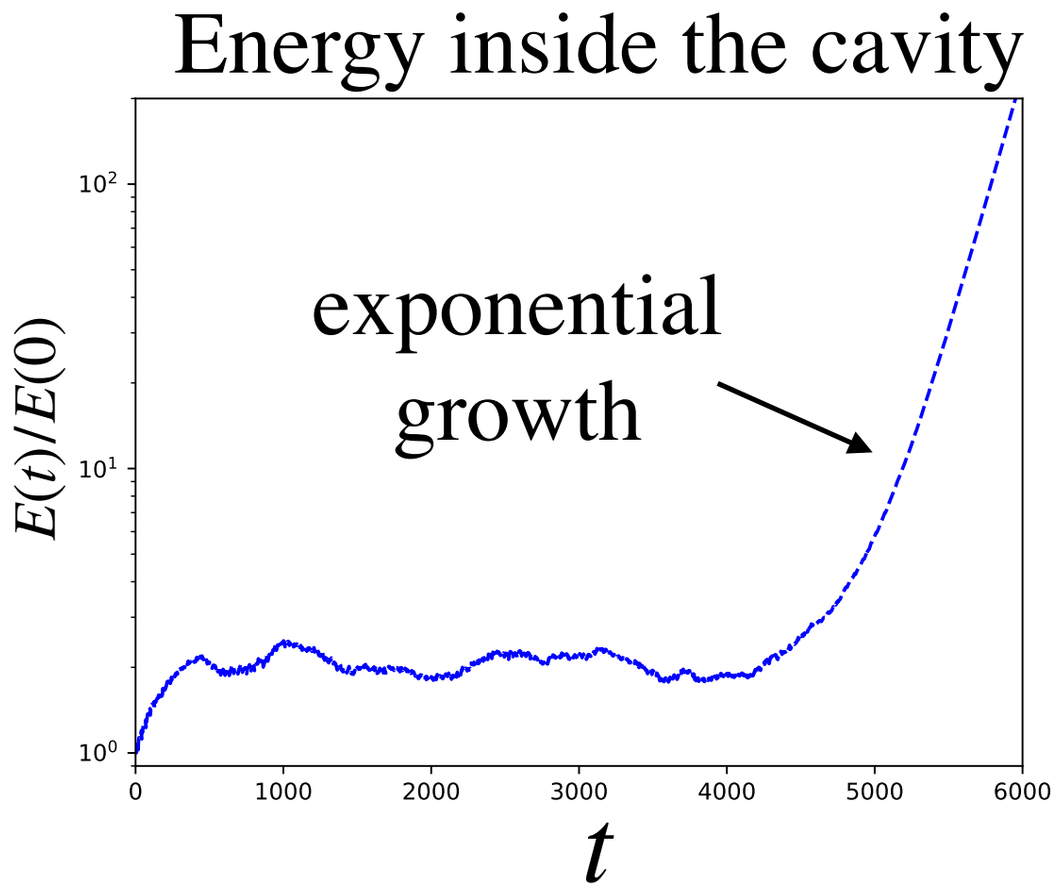




$R_{\text{ext}} = 30,\ \Omega = 0.14,\ r_{\text{b}} = 0.5$



Summary

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- We consider the fundamental properties of binary BH spacetime.
- Result
  - closed null geodesic around BHB
  - global QNM in BHB spacetime
  - Exponential growth of energy of scalar field (in toy model)
- Ongoing work (BHB bomb)
  - Does BH binary bomb exist ?
    - scalar field around BHB in cavity
    - vector field around BHB in cavity

Thank you for your attention.